EIC Detector R&D Progress Report
Reporting Period: From NOV 2012 to MAY 2013

Project Name: Proposal for detector R&D towards an EIC detector

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Past

What was planned for this reporting period?

Various projects from the various groups were planned for the reporting period and will be described in the following.

The *BNL group* focused on the development of a mini-drift GEM detector and the design of a fast, compact TPC with a GEM readout combined with particle ID capabilities using a separate photosensitive GEM detector to detect Cherenkov light.
The *Florida Tech group* was planning to hire a postdoc for the hardware projects, the design and fabrication of PCBs with zigzag strip readout and the integration of zigzag PCBs into triple-GEM detectors as well as the testing of their performance.
The *Stony Brook group* planned to perform a test-beam campaign with the HBD-RICH prototype with a modified readout board and to develop the techniques for producing large mirrors in house.
The plan of the *UVa group* was to design and develop a large area mechanical stretcher for large area GEM foils and to finalize the design of the large area GEM module.
The *Yale group* planned to test the 800 μm readout board with sources and cosmic rays and to produce in a test-beam proposal and scheduling.

What was achieved?

BNL group:

Progress on the minidrift GEM detector focused mainly on the analysis of the test beam data taken at CERN in October 2012. Improvements were made to the alignment of our detector with the set of micromegas detectors that were being tested by the ATLAS group in the same beam line which we use as a beam telescope to determine the position and angle of beam tracks in our detector. Due to the long lever arm between the two detectors (~ 1.5 m), the relative alignment between them is very important. Figure 1 shows the residual distribution between the position coordinate found in our GEM detector at normal incidence to the beam compared to the extrapolated track from the micromegas system. The resolution is ~ 140 μm in both X and Y, and the error on the extrapolated track is ~ 100 μm, which gives a resolution ~ 100 μm for the GEM detector. We feel that this can be further improved with better alignment between the two detectors and better selection on track quality. Data with the GEM detector at other angles to the beam are also being analyzed.

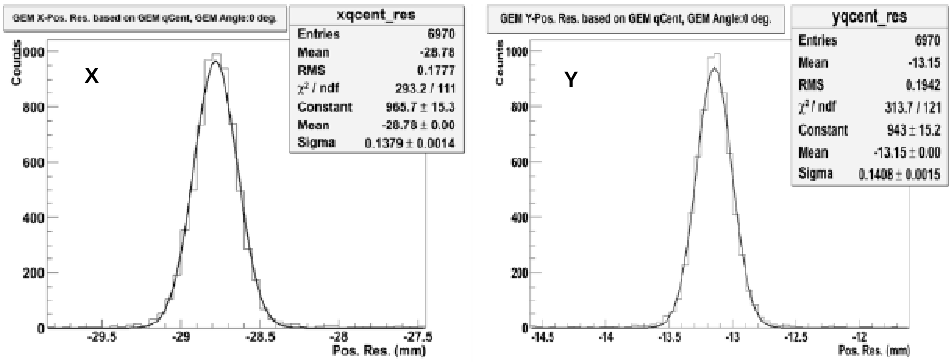

Figure 1 Residual distributions between the track positions found in the mini-drift GEM detector compared to the extrapolated track position from the set of micromegas detectors. The contribution from the extrapolated track is ~ 100 μm, implying that the position

Progress was also made on the design of the prototype TPC/Cherenkov detector. The current detector model is shown in Figure 2. The effort over the past several months has focused on detailing the design of the field cage and it associated mechanical components. An important design consideration is the electrical connections of the wire plane to the main part of the field cage. A possible scheme for doing this is shown in the detail in Figure 3.

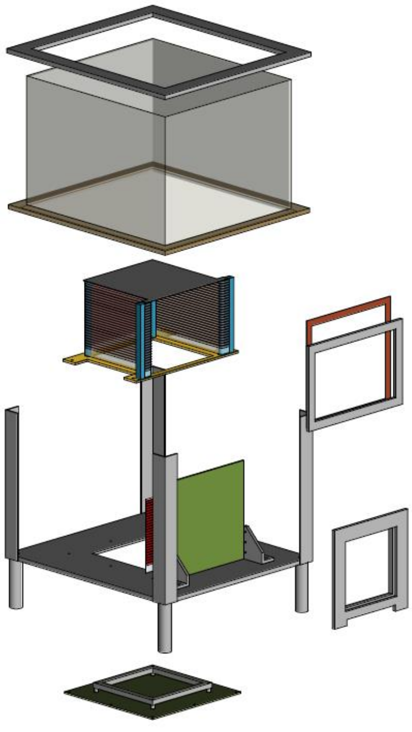

Figure 2 Current 3D model of the prototype TPC/Cherenkov detector.

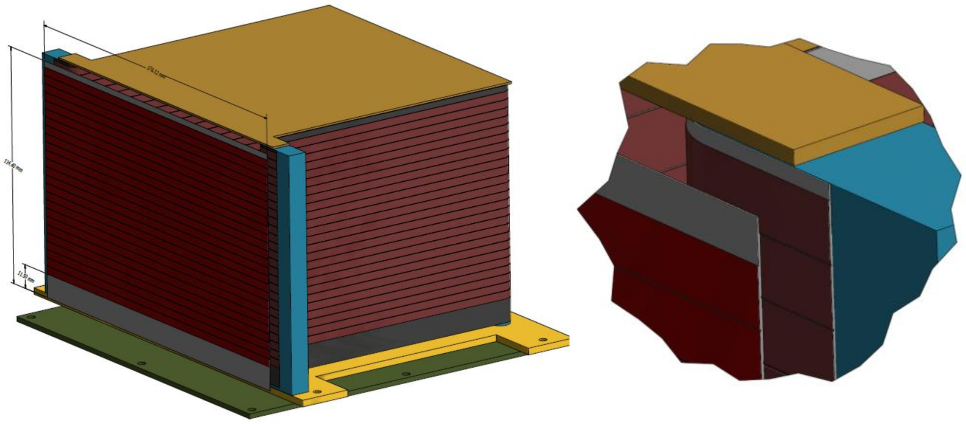

Figure 3 Detail of the main TPC field cage and connection to wire plane portion.

In order to design the actual field cage, a full electrostatic simulation is required. We now have a collaborator (Prakhar Garg from Banaras Hindu University in India) who has begun to do this simulation for us using Ansys. We expect to have some first results from this calculation within the next few weeks.

In addition to developing the prototype model, we also carried out drift velocity measurements in Ar/CO_2 and ion mobility measurements in Ar/CO_2, Ne/CO_2 and Ne/CF_4 gas mixtures. We are now also modifying our drift cell test setup to allow us to make drift velocity measurements in neon gas mixtures.

Florida Tech group:

Upon arrival of EIC funding at Fl. Tech in Sep 2012, an international search for a post-doc was begun. About 20 applications were received and reviewed. A search committee, comprising senior consortium members from BNL, SBU, and UVa and chaired by Fl. Tech, conducted video interviews with the top five candidates. On behalf of the project, Fl. Tech extended an offer for an initial one-year contract to Dr. Aiwu Zhang from IHEP Beijing, which he accepted. Fl. Tech produced the visa paperwork and Dr. Zhang arrived there on May 20 to start his position on June 1, 2013. He will be based at Fl. Tech, but will also support EIC R&D efforts at BNL, SBU, and UVa, which will include travel to all the sites.

Undergraduate students have been laying out a 30cm × 30cm PCB with zigzag strips in various geometric patterns using Altium circuit design software (see Figure 4). Layout of 2/3 of the board with rectangular strip geometries is complete; layout of radial patterns as needed in an actual trapezoidal forward tracking chamber has started.

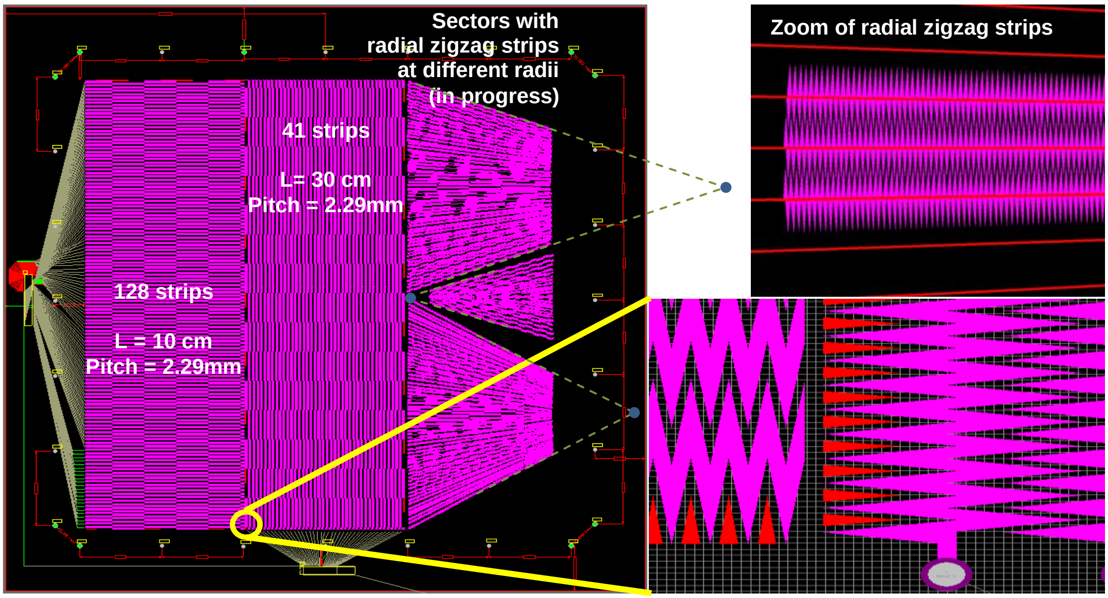

Figure 4 Design of 30cm × 30cm test PCB with zigzag strips for S4.

Students tested two 10cm x 10cm Triple-GEM detectors with zigzag-strip readout PCBs in an X-ray test stand that was commissioned at Fl. Tech to measure the gas gains of these detectors. We had tested the resolution of these detectors in muon/pion test beams at CERN earlier in 2012. Results from the beam test using the Scalable Readout System (SRS) confirmed an expected resolution of better than 100 microns for normally incident particles; a 73 micron spatial resolution was measured. These results were presented at the 2012 IEEE Nucl. Sci. Symp. in Nov 2012 and published in the proceedings.

A 30cm x 30cm self-stretching sans-spacer (S4) Triple-GEM with COMPASS-style x-y readout was assembled by a student using parts produced by CERN. The new assembly technique was demonstrated to a collaborator from UVa (K. Gnanvo) during his visit in Dec 2012 as part of on-going know-how transfer within the consortium. This detector is now operational and is being tested with X-rays. One HV sector in one GEM foil was found to be faulty and had to be disconnected. The rate plateau and the uniformity of the signal response were surveyed as a function of position. A signal could be picked up from the bottom of the third GEM foil of this detector to trigger the SRS. The detector is now instrumented with 12 APV25 hybrids and X-ray data are being acquired and analyzed using the DATE and AMORE software for the SRS.

Stony Brook group:

We finished a parasitic test–beam campaign in Hall A of Jefferson Lab which was inconclusive since the conditions have significantly changed after our arrival. Consequently, no useful data could be collected but operating experience could be acquired as well as design issues could be reiterated. This led to a modified design of a readout board which has now hexagonal pads in contrast to the before used COMPASS-style strip readout.
The setup used at JLab has been shipped and installed in the ESTB area of SLAC where another test-beam campaign has just started.

On May 14, six members of the Stony Brook team arrived at SLAC to perform the beam tests on the modified detector. Two arrived by truck carrying the detector (faculty Hemmick, grad student Zajac), and four by air (faculty Deshpande & Dehmelt, postdoc Feege, and undergraduate Blatnik). Installation of the detector proceeded smoothly (Figure 5), including recorded signals from ^{55}Fe, and gas purities of below 1 ppm for both oxygen and water.

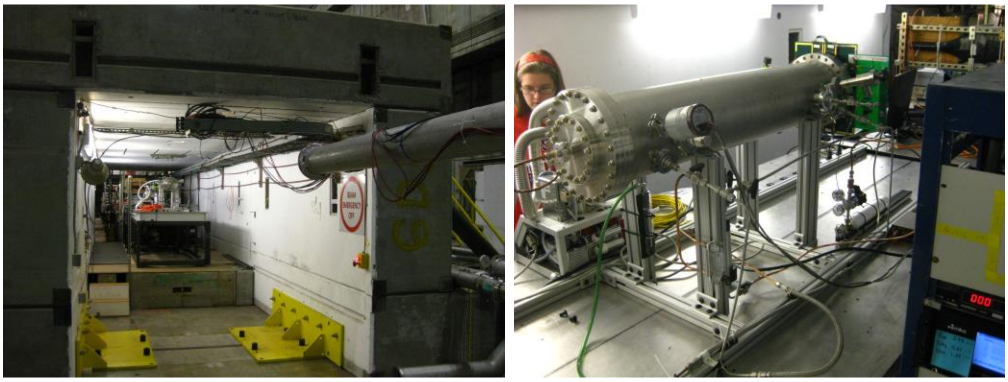

Figure 5 SLAC test-beam setup. Left: Detector table in the beam line. Right: Preparing the detector for operation.

On May 15, first beam was delivered in the evening and setup of the electronics began. A set of very short trigger scan runs were completed with the detector at only moderate voltage. Following these trigger scan runs, an overheating of a switchyard kicker magnet (used to supply beam to our apparatus) ended the beam time prior to taking real data. The correct DAQ timing run was only 72 seconds in length, but nonetheless resulted in first observations of signals (Figure 6) and rings as shown in Figure 7.

The kicker magnet has been repaired (incorrect cooling water plumbing) and tested. Our data will be collected starting on the last day of May or first day of June. From the timing run data, and accounting for its less than nominal operating voltage, we expect that the final data will produce results meeting or exceeding the design goals for this device.

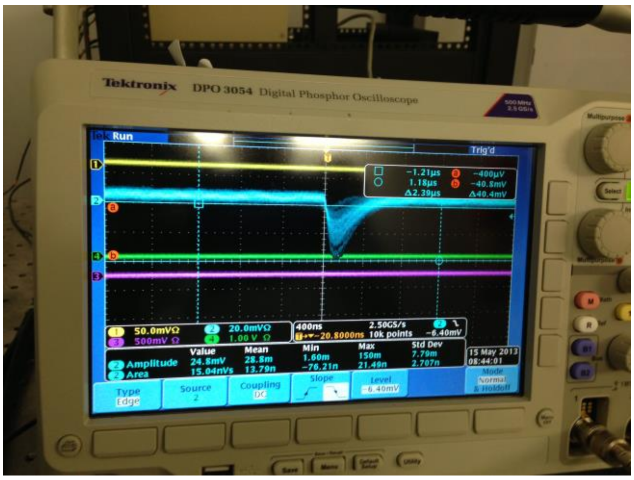

Figure 6 Signals of particle traversing HBD-RICH.

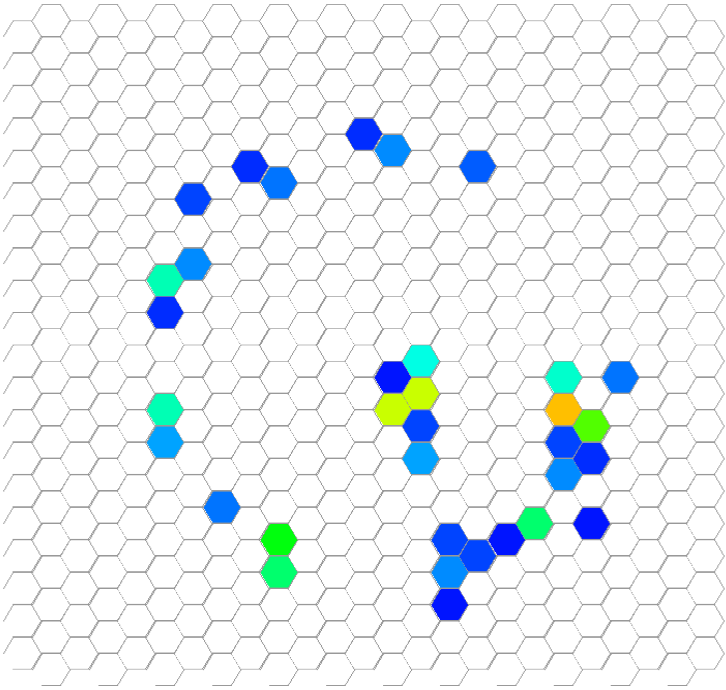

Figure 7 Cherenkov ring image recorded with the HBD-RICH prototype.

The major advance in the mirror work is the recognition via earlier tests that the 10^{-6} torr achieved in the Big Mac tank is only marginally adequate. We have identified two large capacity turbo pumps that are in hand and can be additionally added to the Big Mac to put the vacuum spec for that device into the save range for reliable mirror production.

UVa group:

We developed the concepts needed for the large foil stretcher. These were tested on a foil stretcher we fabricated for 50 x 50 cm^2 GEM foils. One main idea we wanted to test was the fabrication of stretcher components using hard plastic instead of aluminium. This was crucial because we previously discovered that aluminium dust from stretcher parts tend to contaminate GEM foils leading to shorted sectors. We stretched 6 GEM foils using the 50 x 50 cm^2 stretcher; the stretching process and the tests of stretched foils indicate that the stretcher works very well. Based on this success we are now designing the large foil stretcher proposed under this program.
We completed the final design of the large area EIC prototype GEM Chamber. Dr. Kondo Gnanvo travelled to CERN and worked closely with the designers there to finalize the design of the chamber. The orders for the components were placed and they are currently being fabricated at CERN. Figure 8 shows the finalized design for this GEM module.

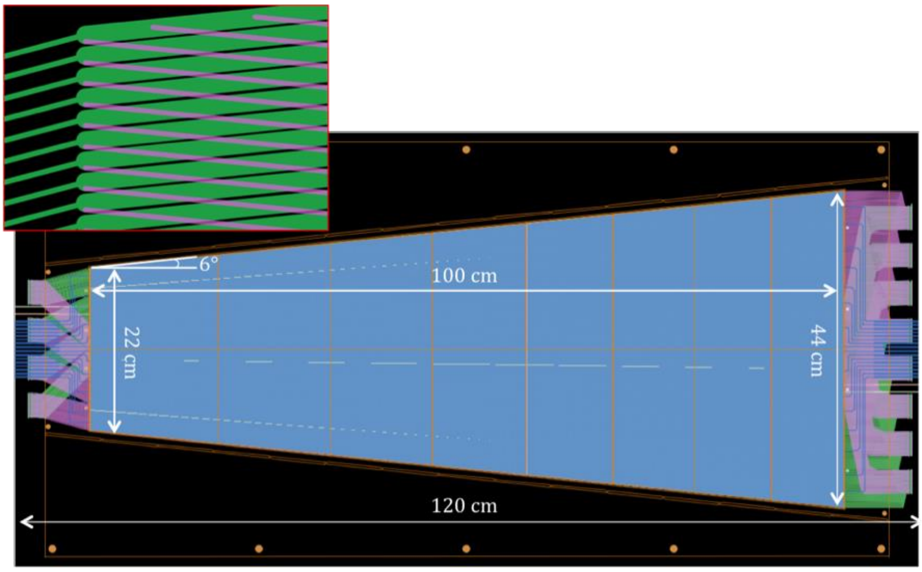

Figure 8 Final design for the large area GEM prototype with 2D readout. The insert in the upper left .corner shows a zoomed in section of the readout. The angle between the two sets of strips is 12^{o}.

Yale group:

Some 800 μm chambers have been assembled and tested with a ^{55}Fe source. Quality issues with one batch of GEM foils have slowed the final assembly. One year delivery time for the DAQ system has slowed the cosmic ray testing. The system is in hand now and we are currently setting it up and learning to use the software.
The proposal for test beam running was submitted and accepted. We are scheduled to run (T1037) for 3 weeks in October.
Funding to support this effort (the second part of last year's funding) still has not been allocated.

What was not achieved, why not, and what will be done to correct?

BNL group:

We did not complete the analysis of the CERN test beam data due to technical difficulties in implementing the ATLAS micromegas detector tracking package on our computer. We have now acquired a new computer and managed to get that software package working and expect the analysis to proceed more quickly.

We have not completed the 3D model or electrostatic simulation of the prototype TPC/Cherenkov detector. The design of the 3D model is complicated and requires time from both physicists, engineers and designers, which has been limited. The expertise for doing the electrostatic simulation has just become available to us and work on this calculation has begun.

Florida Tech group:

The development of the 30cm × 30cm PCB with zigzag strips in various geometric patterns has progressed steadily, but more slowly than anticipated. This is mainly due to the inexperience and limited availability of the undergraduate students working on this. We expect to speed this up soon with help from the post-doc.

Stony Brook group:

Data could not be collected at the beam-test at JLab as the conditions during our parasitic runs have changed such that literally no electron was traveling through our detector setup so that a useful ring event could be recorded. For correcting this dilemma our group has applied for a test-bam campaign at SLAC and successfully started this endeavour.
For the mirror development we have identified two large capacity turbo pumps that are in hand and can be additionally added to the Big Mac to put the vacuum spec for that device into the save range for reliable mirror production.

UVa group:

We initially intended the 2D readout for the large GEM module to be of the single layer pad-strip type; similar to SBU/Yale readout boards. However, the company that produced their readouts, Tech-Etch, informed us that their technology does not allow for readout boards as long as 1 m needed for the proposed GEM module. On the other hand Rui De Oliveira, the CERN GEM foil and readout board Guru, agreed to work with us to develop a 1 m long 2D readout based on the 2 layer COMPASS readout design. We designed this readout board and it is under fabrication at CERN now; Figure 8 shows the details of the readout. This is the first 2D readout developed for a 1 m size GEM chamber and represents a major milestone in large area GEM chamber technology.

Yale group:

As indicated above, an issue with the quality (gain and gain uniformity) slowed the final assembly of some chambers. We now have enough foils of acceptable quality to complete the assembly.
Long lead time for delivery of the DAQ system has slowed cosmic ray testing. The system is now in hand and testing will begin soon.
The second part of the funding to support the test beam effort (construction of fixtures and travel) has not yet been allocated.

Future

What is planned for the coming months and beyond? How, if at all, is this planning different from the original plan?

BNL group:

We hope to complete the analysis of the CERN test beam data during the next few months. This will include measuring the position and angular resolution of the mini-drift GEM detector over the full range of angles taken at the test beam. We are also planning further tests of the mini-drift detector at Fermilab later this year.

We also hope to complete the 3D model of the TPC/Cherenkov prototype along with the electrostatic simulation of the field cage during the next several months. The main items requiring further detail are the readout plane and its connections, and incorporating the photosensitive GEM detector in the assembly. Once the 3D model and electrostatic simulation are complete, construction of the prototype can begin. Additional drift velocity and ion mobility measurements will also be carried out using neon gas mixtures.

Florida Tech group:

Once the design of the 30cm × 30cm PCB with zigzag strips is finished, we plan to have it fabricated by industry. After replacing the GEM foil with the faulty HV sector with a spare foil and full characterization of the 30cm x 30cm S4 Triple-GEM detector using the COMPASS-style x-y readout, we will replace the x-y readout with the new zigzag readout board. We will re-commission the new zigzag prototype detector with X-rays at Fl. Tech and prepare it for a beam test at Fermilab.

In parallel, we plan for the post-doc to design a zigzag readout PCB for a full-size trapezoidal large-area (100cm × 45cm) Triple-GEM prototype detector and to fabricate a few of these large PCBs in industry. We plan to assemble two such prototype detectors with zigzag readout and to test them with X-rays. If these detectors become available in time, we will also test them in the Fermilab beam. Together with a large-area GEM with u-v readout produced by UVa, a three-station slice test of a GEM forward tracker for the EIC detector could then be conducted at the Fermilab test beam. Such a slice test was envisioned as the goal of the two-year R&D period in the original proposal. If there are delays in the design or production of these prototypes, such a slice test could be done in a second beam test at a later time when all chambers will be in hand.

Stony Brook group:

The test-beam campaign at SLAC will be continued and systematic studies will be performed (Figure 9). The tests are being performed with electrons so only proof of principle studies can be performed. We have applied to yet another test-beam campaign with all our fellow groups which will be performed in the first three weeks of October this year. This test-beam will include a variety of particle species and momenta so that the performance of our HBD-RICH prototype with respect to particle identification can be studied and shown.

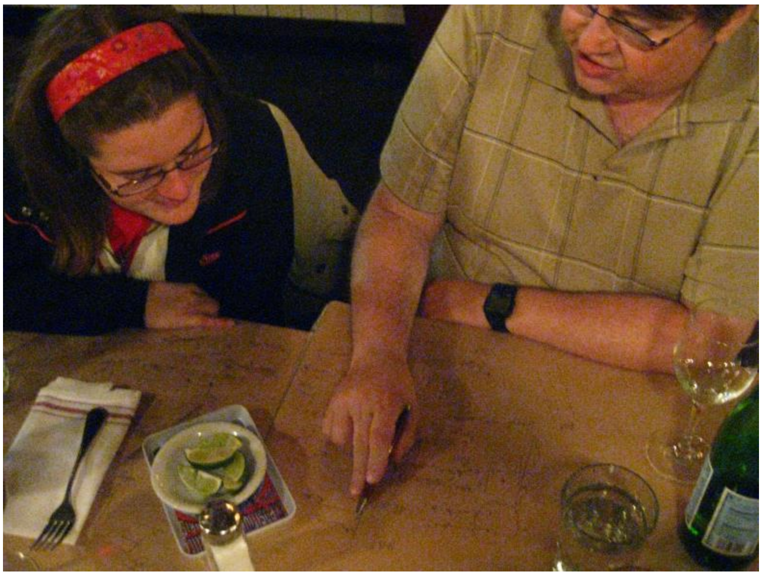

Figure 9 Systematic studies to be performed.

UVa group:

May 2013 – July 2013: Complete the design of the large GEM foil stretcher and fabricate it. Test and evaluate the performance of the stretcher during the construction of the large GEM chamber.
July 2013 – October 2013: We expect to receive all components for the large GEM chamber by July; we plan to finish its assembly by September, in time for the beam test at Fermilab in October.
October 2013 – September 2014: Assemble a dedicated SRS readout system for the GEM chamber. Use this readout to test characterize the chamber.

Yale group:

We plan to have the 800 μm pitch chambers under cosmic ray tests through spring and early summer. We will also assemble the 600 μm pitch chambers in the summer and have those tested before the test beam run at Fermilab. The three week test beam run at Fermilab will allow final characterization of both sets of chambers.

What are critical issues?

BNL group:

Understanding the position and angular resolution of the minidrift GEM detector.
Electrostatic and mechanical design of the TPC/Cherenkov detector.

Florida Tech group:

Production of large zigzag boards as well as assembly and testing of the second large-area Triple-GEM chamber require purchase of parts and additional SRS electronics modules from CERN. These were budgeted for the second instalment of approved 2013 funding, which has not yet been received at Fl. Tech. The formal funding request was sent to BNL in March 2013. The funds are also critical to support team-member travel to the Fermilab beam test.

Stony Brook group:

For the mirror development we have identified two large capacity turbo pumps that are in hand and can be additionally added to the Big Mac to put the vacuum spec for that device into the save range for reliable mirror production.
For adding the turbo pumps to the Big Mac it is necessary to produce a flange for each pump. The production of these two flanges (90 degree flanges with 18" openings) will cost roughly $10,000.
In order to pursue our test-beam efforts at SLAC and Fermilab it is critical that we receive additional moderate funding.
Unfortunately the costs for running at SLAC (now that we are running twice) have been higher than anticipated by roughly $8,000. Thus, we will require an additional total of $18,000 (+ overhead) or $28,440 to continue to meet our design goals for this work.

UVa group:

In the initial FY 13 funding request submitted with the proposal, the UVa group asked for funding for a SRS readout system to test the large GEM chamber ($ 10,000), travel ($ 7,000), materials and supplies ($1,500) and engineering and technical support ($ 7,500). However, due to reduced funds allocation to this project, the funding for travel was reduced by $4,000 while funding for the other items above was removed altogether in the final FY 13 budget. This reduction will severely affect our progress going into the planned activities for the next year. Especially, the lack of funds for the SRS electronics to test the chamber we are constructing and the lack of travel funds to support the visits by the shared post-doc to participate in the chamber testing would be especially detrimental.

Therefore, we would like to ask funding at the level of $ 30,540 in the current funding cycle to cover the expenses listed above. ($ 30,540 including $23,000 direct costs: SRS electronics $ 10,000, travel $ 4,000, materials and supplies $1,500, engineering and technical support $ 7,500 + $ 7540 indirect costs)

Yale group:

It is vital that the remaining part of last year's funds be available soon to allow design and construction of the infrastructure for the test beam run scheduled in October and to allow a trip to Fermilab to complete the required training and assess the details of what will be needed for the run.

Additional information:

BNL group:

Florida Tech group:

Contributors at Fl. Tech: V. Bhopatkar (grad student), M. Phipps, E. Starling, J. Twigger, K. Walton (undergraduates)

Stony Brook group:

Budget request

Item	Cost (in US-$)
2 x 90^0 flanges with 18" openings	10,000
Test-beam efforts at SLAC	8,000
Overhead (58%)	10,440
Sum	**28,440**

UVa group:

Budget request

Item	Cost (in US-$)
SRS electronics	10,000
Travel	4,000
Materials and supply	1,500
Technical support	7,500
Indirect costs	7,540
Sum	**30,540**

Yale group: